

ESTIMATION OF PLANETARY CONTAMINATION PROBABILITIESDUE TO FLIGHT OF THE U.S.S.R. VENUS 3*

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- Enclosures: (a) Nomenclature
- (b) Report in Spaceflight, Vol.8, No.5,
May 1966, p.163 on "Soviet Venus Probes"
- References: (1) NASA position on COSPAR resolution 26.5
submitted to COSPAR Meeting at Vienna,
May 1966, including supporting documentation
- (2) "Analysis of Planetary Quarantine Requirements"
by S. Schalkowsky & W.C. Cooley, dated 5 April 1966
- (3) Aviation Week and Space Technology, March 14, 1966
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I. INTRODUCTION

As described in enclosure (b), Venus 3 was launched by the U.S.S.R. on November 16, 1965 with the intention of delivering a capsule to the surface of Venus. In accordance with published reports, i.e. enclosure (b) and reference (3), the landing mission failed. Furthermore, the spacecraft reportedly impacted the planet thus leading to speculation that Venus might already be contaminated. Since planned and future missions to Venus are subject to planetary quarantine constraints, interest focuses on the question whether these constraints require a quantitative re-evaluation in the light of the Venus 3 flight. Specifically, it is often stated or implied that in view of the high probability of planetary contamination by Venus 3, future

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missions should not be subjected to the same stringent constraints which would otherwise be appropriate. The analysis which follows attempts to deal with this question.

In addition to the uncertainties inherent in any estimation of planetary contamination probabilities, this analysis is subject to uncertainties associated with the sources of information on the flight of Venus 3. The extent of available information is typified by the report of enclosure (b) and reference (3). Furthermore, even the validity of available information is, in some cases, subject to question. For example, the claim by the U.S.S.R. that "the descending apparatus" was sterilized is in itself inadequate because of a lack of quantitative data. However, since this claim was made after the fact, and in view of related historical background, the truthfulness of the claim itself is sometimes questioned. To reach meaningful conclusions in the presence of all of the above uncertainties, the approach taken here is to cast the problem in the same framework used by NASA to evolve planetary quarantine constraints, i.e. reference (1), so as to permit a relative rather than an absolute estimate. In addition, the analysis will consider two limiting cases to represent the bounds on the probabilities of planetary contamination due to Venus 3 and the corresponding consequences for future Venus missions.

II. SOURCES OF CONTAMINATION

Although the question of planetary temperatures for Venus is far from being settled, there appears to be a consensus on the fact that the only regions where terrestrial micro-organisms could survive are the polar caps and in some portion of the atmosphere. As described in enclosure (b), there is adequate basis to assume that Venus 3 impacted in the equatorial regions of the planet. The only cause of planetary contamination to be considered here will, therefore, be the presence of terrestrial micro-organisms in the atmosphere of Venus.

Following the procedures of the supporting documentation in reference (1), we will make a distinction between contamination due to the sterilized probe and the various sources of contamination associated with the unsterilized spacecraft. In general, the latter category requires consideration of the following:

- (1) impact of entire spacecraft
- (2) recontamination of sterilized probe with unsterilized micro-organisms from spacecraft
- (3) ejecta from attitude control gases
- (4) ejecta from mid-course motor
- (5) micro-meteorite spalling products
- (6) outgassing products

Table I, below, will serve to identify the boundary cases for the analysis. The matrix of conditions contained in this table derives from the uncertainty as to whether the sterilized probe has indeed been released into the atmosphere and whether the vehicle carrying the probe impacted the atmosphere. (Numbers in parenthesis in the row of sources of contamination refer to the listing given above for the unsterilized spacecraft.)

Table I

	Probe Released	Spacecraft Impacted	Sources of Contamination						
			Ster. Probe	(1)	(2)	(3)	(4)	(5)	(6)
I	Yes	Yes	x	x	x	x	x	x	x
II	Yes	No	x		x	x	x	x	x
III	No	Yes		x		x	x	x	x
IV	No	No				x	x	x	x

Since Case I contains all of the possible sources of contamination, it will give the upper bound in the analysis. Case IV would appear to be

the lower bound since it contains the fewest sources. However, it implies that neither the probe nor the spacecraft reached the atmosphere of Venus which is inconsistent with the basic premise of this analysis and conflicts with the conclusion reached by the U.S.S.R. from numerous measurements during the transit of Venus 3. This case is therefore excluded from further consideration. As regards cases II and III, conclusions as to which is the lower bound is best deferred to the point in the analysis when numerical values are applied. We will thus examine three cases, corresponding to I, II and III in Table I.

III. ANALYTICAL FRAMEWORK

In general, the nomenclature to be used here is as given in enclosure (a) and is identical to the proposed standard nomenclature of references (1) and (2). In addition, we define the following terms:

P_C^* - total probability that Venus was contaminated by the flight of Venus 3

P^* - probability that Venus was contaminated by the sterilized probe of Venus 3

P'^* - probability that Venus was contaminated by the Venus 3 unsterilized spacecraft.

Assuming that we will deal with values of P^* and P'^* much less than unity

$$P_C^* = P^* + P'^* \quad (1)$$

We can expand the probabilities P^* and P'^* as follows (see reference (2)):

$$P^* = P_N \cdot P_R \cdot P_G \quad (2)$$

$$P'^* = \sum_{i=(1)}^{i=(6)} (P_T' \cdot P_R' \cdot P_G')_i \quad (3)$$

The notation in equation (3) for i refers to the listing of contamination sources given in Section II, i.e. $i=(1)$ refers to impact of the entire spacecraft etc.

CASE I: (Spacecraft impacted and probe entered atmosphere)

It will be convenient to group the various component probabilities as follows:

$$P_I^* = P_N \cdot P_R \cdot P_G + (P_T' P_R' P_G')_{(1)} + (P_T' P_R' P_G')_{(2)} + \sum_{i=(3)}^{i=(6)} (P_T' P_R' P_G')_i \quad (4)$$

The last term in equation (4) can be neglected since it is much smaller than the second term which deals with impact of the spacecraft. This can be justified on the grounds that (1) a probability of unity is assigned, in this case, for the spacecraft being present in the atmosphere of Venus but the probability of ejecta, spalling products and outgassing products reaching Venus is much less than unity for each of these events, (2) the probability that micro-organisms will be released in a viable state into the atmosphere is smaller for the small particles associated with ejecta than it is for the spacecraft, and (3) the probability of growth, p_G' , is at worst equal and, more likely, it is smaller for the various cases of ejecta because smaller numbers of viable organisms are involved. Equation (4) thus reduces to:

$$P_I^* = P_N \cdot P_R \cdot P_G + (P_T' \cdot P_R' \cdot P_G')_{(1)} + (P_T' \cdot P_R' \cdot P_G')_{(2)} \quad (5)$$

Although Case I can be studied on the basis of equation (5), it seems reasonable to also make $p_R \cdot p_G = p_R' \cdot p_G'$ on the basis that although p_R , the probability of release from the landing probe, is greater than p_R' because of the larger areas associated with a parachute, this would be balanced by the fact that p_G' should be taken to be larger than p_G , i.e. that viable organisms which have not been subjected to a sterilizing environment are more likely to grow and spread. On this basis, Case I reduces to:

$$P_I^* = P_R' \cdot P_G' \left[P_N + P_T' (1) + P_T' (2) \right] \quad (6)$$

Since the procedures used to sterilize Venus 3 are not known in detail it will be difficult to select an appropriate value for p_N . However, this problem does not exist in the present case since, again, we would be adding p_N to $p_T'(1)$ and the latter is assumed to be unity. Thus, even if p_N is taken as large as 0.1, it can be neglected in relation to $p_T'(1) = 1$. We can therefore use

$$P_I^* = P_R' P_G' \left[p_T'(1) + p_T'(2) \right] \quad (7)$$

CASE II: (Spacecraft did not impact, but probe entered atmosphere)

Since the dominant source of contamination associated with impact of the spacecraft is not present here, the various ejecta terms can not be immediately neglected. However, we may retain the simplification resulting from the assumption that $p_R \cdot p_G = p_R' \cdot p_G'$. P_{II}^* is thus

$$P_{II}^* = P_R' \cdot P_G' \left[p_N + p_T'(2) + \sum_{i=(3)}^{i=(6)} (p_T')_i \right] \quad (8)$$

CASE III: (Spacecraft impacted, probe not deployed)

An equation for this case can be obtained by dropping the appropriate terms in equation (6) to give

$$P_{III}^* = P_R' \cdot p_G' \cdot p_T'(1) \quad (9)$$

IV. NUMERICAL ESTIMATES

For convenience, the equations for the three cases developed in Section III are summarized below:

$$P_I^* = P_R' \cdot P_G' \left[p_T'(1) + p_T'(2) \right] = P_R' \cdot p_G' \cdot Q_I \quad (7) a$$

$$P_{II}^* = P_R' \cdot P_G' \left[p_N + p_T'(2) + \sum_{i=(3)}^{i=(6)} (p_T')_i \right] = P_R' \cdot p_G' \cdot Q_{II} \quad (8) b$$

$$P_{III}^* = p_R' \cdot p_G' \cdot p_T'(1) = p_R' \cdot p_G' \cdot Q_{III} \quad (9)c$$

It will be noted that in each of the three cases the product $p_R' p_G'$ has been separated out of the summation in the parenthesis. This was done to permit a distinction between parameters which relate to conditions at the planet and are independent of the quarantine precaution taken by the U.S.S.R., and parameters which require judgment as to what the Russians did or did not do. The parameters in parenthesis represent the latter category and will be referred to as quarantine parameters. Their sum will be denoted as Q , as shown in equations (7)a thru (9)c above. p_R' and p_G' will be referred to as planetary parameters.

An estimate of the quarantine parameters will be made first in the form shown in Table II. Where applicable, two values are given to represent the upper and lower bounds of the estimate.

Table II

	$p_T'(1)$	$p_T'(2)$	$\sum_{i=3}^{i=6} (p_T')_i$	p_N	Q
CASE I	1	$\frac{0.5}{10^{-3}}$	N.A.	N.A.	1 - 1.5
CASE II	N.A.	$\frac{0.5}{10^{-3}}$	$\frac{10^{-3}}{10^{-5}}$	$\frac{10^{-1}}{10^{-3}}$	$0.6 - 3 \times 10^{-3}$
CASE III	1	N.A.	N.A.	N.A.	1

The rationale for choosing the various numerical values in Table II may be summarized as follows:

$p_T'(1)$ - probability that spacecraft entered atmosphere.

In cases I and III this is taken to be a certainty and a value of 1 is used.

$p_T'(2)$ - probability that probe was recontaminated by unsterilized spacecraft.

It is assumed that the Russians did not take precautions of the type considered necessary by NASA, i.e. the provisions of a sterility barrier, and a relatively large probability of recontamination is therefore used.

$\sum_{i=(3)}^{i=(6)} (p'_T)_i$ - probability that various ejecta will reach the atmosphere.

The range of values used is generally compatible with data from NASA supported studies on these sources of contamination. It is also noted that Venus 3 mid-course and retardation motors were apparently not operated near the planet thus justifying low values for this parameter.

p'_N - probability of one surviving micro-organism on the sterilized probe:

The lower value of 10^{-3} compares to the probability of one survivor inherent in current NASA requirements. Since it is not at all certain that the sterilization techniques applied to Venus 3 will give this level of sterility assurance, an upper bound of $p_N = 10^{-1}$ is also used.

Table II indicates that Case III is not essential for further consideration since it gives a value of Q not significantly different from Case I. Case I, which assumes impact of the spacecraft and deployment of the probe, will thus give the upper bound for the probability of contamination by Venus 3. The lower bound must be derived from Case II, which, as will be recalled, is conditional on the assumption that the spacecraft did not impact the planetary atmosphere, i.e. it was on a flyby trajectory which permitted injection of the probe. Further assuming that injection did take place, the value of Q_{II} in the range of 6×10^{-1} to 3×10^{-3} would depend on the care with which the Russians sterilized the probe and then protected it from recontamination. In view of all of the above considerations it appears prudent not to use a value for Q_{II} near its lower range. We will therefore calculate lower limits of the probability of planetary contamination using $Q_{II} = 5 \times 10^{-2}$.

To complete the numerical estimate, it is necessary to select suitable values for the probability of growth, p'_G , and the probability of release of viable organisms, p'_R . Although there is little basis at present for justifying a particular value of p'_G , the general impression given by those

writing on the subject is that it would be less than unity. To obtain a conservative estimate, we will use $p'_G = 0.1$.

In the case of p'_R , we are concerned with the passage of the probe, the spacecraft or various ejecta through the atmosphere of Venus and we are looking at two opposing events. Thus, on the one hand, there must be an aerodynamic force to remove material containing terrestrial micro-organisms and retain them in the atmosphere sufficiently long to produce growth. On the other hand, these forces can not be so high as to render the organisms sterile in the process of removal. Allowing for a parachute descent and favorable pressure and temperature gradients in the atmosphere, the probability of releasing viable organisms can not be completely discounted. However, it would also not be reasonable to assign a large value to this probability. We will use 10^{-2} as a conservative estimate for p'_R .

The upper and lower bounds on the probability that Venus 3 contaminated the planet thus become

$$P_I^* = p'_G \cdot p'_R \cdot Q_I = (10^{-1})(10^{-2})(1.5) = 1.5 \times 10^{-3}$$

$$P_{II}^* = p'_G \cdot p'_R \cdot Q_{II} = (10^{-1})(10^{-2})(5 \cdot 10^{-2}) = 5 \times 10^{-5}$$

V. DISCUSSION

In assessing the implications of the Venus 3 flight on future missions on the basis of the analysis presented herein, the following is to be noted:

(a) Future missions must take into consideration the possibility of landing in the polar regions of the planet, thus introducing a source of contamination not applicable to the Venus 3 flight.

(b) The major reason why estimated probabilities of contamination by Venus 3 are substantially less than unity, i.e. between 1.5×10^{-3} and 5×10^{-5} , is that the planetary parameters p'_G and p'_R are estimated to be

small. Thus, even though the man-made events may not have been such as to reduce the probability of introduction of a micro-organism in the atmosphere, Venus is nevertheless not expected to have been contaminated because of the unfavorable environment on this planet to the release and growth of terrestrial organisms.

Reference (1) defines the goal for planetary exploration in terms of a probability of less than 10^{-3} that contamination should occur in 100 missions (70 landers and 30 flybys). Using the upper bound of 1.5×10^{-3} estimated here, the allocation for the entire exploration program has been used up by the flight of Venus 3, i.e. the goal of $P_c < 10^{-3}$ can no longer be maintained. Furthermore, if future missions were to give a similar result, i.e. if in every flight the spacecraft were allowed to impact the atmosphere, there is a reasonable chance that, if planetary parameters are of the magnitude estimated here, contamination would occur in 100 flights.

Similar arguments based on the lower bound of $P_c^* = 5 \times 10^{-5}$ indicate that 100 flights under condition similar to Case II, i.e. assuming that the spacecraft did not enter the atmosphere, would lead to $P_c = 5 \times 10^{-3}$. This is also in excess of the goal of $P_c < 10^{-3}$ defined in reference (1).

VI. CONCLUSIONS

To the degree that the various numerical values assumed in this analysis are valid, the following can be concluded:

1. The flight of the U.S.S.R. Venus 3 is not in itself likely to have produced contamination of the planet so as to render all future quarantine precautions unnecessary.

2. Quarantine procedures associated with Venus 3 are not consistent with the goals supported by NASA, as defined in reference (1).

Enclosure (a)

NOMENCLATURE

In the nomenclature defined below, the following symbol categories are used:

(a) Capital P will denote a probability of planetary contamination

(b) Lower case p will denote an event probability which is a component of a planetary contamination probability (P).

(c) Prime superscripts, e.g. P' or p' , will denote probabilities relating to unsterilized organisms. The absence of a prime thus denotes probabilities relating to organisms which have undergone sterilization.

n_L - number of lander vehicles launched over the time-period under consideration. These landers will be sterilized in their entirety prior to launch.

n_U - number of unsterilized buses, orbiters and fly-bys launched over the time-period under consideration.

P - probability that any one landing vehicle, i.e. any one of the n_L 's will contaminate the planet or its atmosphere.

P_U - probability that any one of the unsterilized buses, orbiters, or fly-bys, i.e. any one of the n_U 's will contaminate the planet or its atmosphere.

P_c - probability that the planet will be contaminated during the time-period under consideration.

p_P - probability that one viable organism in a lander previously subjected to heat sterilization, will be present on the planet surface or in its atmosphere.

p'_P - probability that one or more viable organisms not previously heat sterilized will be present on the planet surface or in its atmosphere.

p_G - probability that a viable, but previously heat sterilized, organism present on the planet surface will grow and spread so as to contaminate the planet or its atmosphere.

p'_G - probability that the one or more viable organisms, which have not previously been heat sterilized and are present on the planet surface or in its atmosphere, will grow and spread and contaminate the planet or its atmosphere.

- P_N - probability that one organism on a lander vehicle will remain viable after heat sterilization and transit to the planet.
- P_R - probability that a viable organism if present in a sterilized lander will be released onto the planet surface.
- N - number of viable organisms in a lander after heat sterilization.
- N_0 - number of viable organisms in a lander prior to heat sterilization.
- N_o - number of viable organisms on an unsterilized spacecraft, or portions thereof, at the time it reaches a position to become a contamination hazard.
- N^* - number of viable organisms from an unsterilized spacecraft which are deposited on the planet surface or in its atmosphere.
- P'_T - probability that one or more viable, but previously unsterilized organisms will be transferred from a bus, orbiter, or fly-by to the planet or its atmosphere.
- P'_R - probability that viable, but previously unsterilized organisms transferred to the planet will be released onto the planet surface or into its atmosphere.
- P'_N - probability of one viable organism not previously heat sterilized, on the planet surface or in its atmosphere.

Enclosure (b)

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Soviet Venus Probes

High expectations of the probing of Venus by our Soviet spacecraft Venus 2 and 3 were dashed when the Soviet fleet's landing station in the Corbis failed to receive signals from either craft in the final stages.

Venus 2 launched from the Baikonur complex on 12 November 1965 was estimated to have passed the surface at a planned distance of 20,000 km (12,400 miles) on 17 February. There was no microwave transmission, however, and a primary system for photographing Venus and instruments for making physical measurements of the planet.

When Venus 2 approached the desired position signals from both spacecraft on the microwave receiver system dropped to zero. Information during this time was relayed to the earth by an intermediate relay station system that was designed to relay communications to a relay of 16 communication satellites and eventually relay into earth orbit.

Venus 3 launched on the November 16 designed to deliver a 30-minute relay station to the surface of Venus in orbit. Although the probe was not designed to make a landing with a parachute, it did have a small parachute and a small engine to aid in its descent. The probe was designed to make a landing on the surface of Venus and to remain there for 10 days. The probe was designed to make a landing on the surface of Venus and to remain there for 10 days.

The probe the mission began to descend to the surface of Venus on 17 November 1965. The probe was designed to make a landing on the surface of Venus and to remain there for 10 days. The probe was designed to make a landing on the surface of Venus and to remain there for 10 days. The probe was designed to make a landing on the surface of Venus and to remain there for 10 days.

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